Final Report of the project Grant No. AOARD-10-4140

"Efficient thermal dissipation media for high power electronic chip packaging using CNT-metal based composite"

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I. Introduction:

Currently, challenges in the thermal dissipation of an electronic package arise from the continues increase in power dissipation and power density of higher-power devices, such as high-brightness light emitting diode (HB-LEDs), high power laser diode, solar cell, sensors, etc.

For cost-performance applications, notebooks, telecommunications, MPU heat dissipation levels are forecast to rise from current levels of around 80W to 168W by 2018. This corresponds to heat fluxes of between 57W/cm^2 (2003) and 108W/cm^2 (2016) which must be removed from the single chip package by appropriate cooling techniques [15]. Almost all HB-LED and other electronic pakage manufacturers face the problem of heat dissipation to improve power, performance and efficiency luminescence, etc. The applications of the high power electronic devices seemed to be relying on the effectiveness of thermal dissipation of the packages.

Carbon nanotubes (CNTs) was known as the highest thermal conductivity material compare to other metallic materials (K_{CNTs}=2000 W/m.K compared to K_{Ag}=419 W/m.K and K_{Cu}=380 W/mK). The critical thermal property and the unique nanostructure of the CNTs proved that the CNTs should be an ideal candidate for thermal dissipation media in high power electronic devices [1-9]. This excellent thermal property suggested an approach in applying the CNTs in thermal dispersion materials to solve the mentioned problems. Purpose of the project í to develop the following techniques:

- The technique for making the VA-CNTs film with different thickness and suitable for thermal dispersion measurement on a HB-LEDs.
- The technique for making thermal conducting layer where copper particles covered with the functionalized CNTs.
- The technique for making thermal conducting layer where indium particles covered with the functionalized CNTs.
- Measuring the thermal properties of the VA-CNTs, CNTs/Cu composite and CNTs/In composite with different thickness, different concentration and compare with the currently available thermal matching materials.

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14. ABSTRACT

Vertically aligned carbon nanotube (VA-CNT) films were synthesized and a method was developed to transfer the films from a Si to a Cu substrate. The diameters of the CNTs and the thickness of the films were 10?30 nm and 10?30 ?m, respectively. LED packages made with VA-CNTs films were tested on an InGaN LED chip. The VA-CNTs film maintained a linear relationship of output light power without reaching saturation for the LED chip of 0.5 W InGaN. The VA-CNTs film greatly increased the input LED current, about more than 500 mA and 350 mA, respectively. A homogeneous distribution of multi-wall MWCNTs in a copper matrix was achieved by a novel processing approach based on the precursor method for synthesis of copper and acid-treated MWCNTs. Dispersion of the CNTs in Cu matrix is important and even determined nanocomposite material properties, such as to enhance the mechanical behavior and wear resistance of the Cu/CNTs. Successful functionalization of the nanotubes with mixture of acid solution may open new applications in composites field. Hardness and wear resistance of fabricated Cu/CNTs nanocomposites increased with increasing the mass fraction of CNTs.

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II. Results of the project:

1. Fabrication and application vertically aligned carbon nanotubes (VA-CNTs) films on Cu substrates for thermal dispersion:

a) Fabrication of the VA-CNTs films on Cu substrates:

The VA-CNTs were synthesized by the thermal chemical vapor deposition (CVD) method. The VA-CNTs on Cu substrates were fabricated by two different methods:

- Directly growing the VA-CNTs using thin catalytic metal layers such as Fe/Al or Cr/Al as a catalyst.
- Transferring the VA-CNTs film that was pre-grown on Si substrate to Cu substrate.

*** Direct growth of the VA-CNTs films on Cu substrates:**

To successfully grow the VA-CNTs film, it is necessary to have a high density of catalytic particles on the surface of a substrate. Al/Fe or Al/Cr catalyst films deposited onto thin Cu sheets with the purity of 99.9% were used. An Al layer with a thickness of 15 nm was first deposited on the surface of the Cu substrate by thermal evaporation, and then Fe or Cr layers with thickness levels from 3 nm to 5.5 nm were deposited by sputtering method at room temperature and a base pressure of about 8×10^{-7} Torr. Subsequently, the Cu substrates with Al/Fe or Al/Cr catalyst films were placed in a quartz boat and then inserted into the centre of a quartz tube reactor with a diameter of 2.7 cm housed in a furnace at 400°C. The samples remained at 400°C in air for 10 min. Then, the furnace was heated to 750°C in Ar gas (300 sccm). The H_2 gas (100 sccm) was introduced to deoxidise the Fe or Cr catalyst for 10 min. The VA-CNTs were grown at 750°C for 30 min in the mixture of $C_2H_2/H_2/Ar$ with flow rate ratios fixed at 30/100/300 sccm. After finishing the growing process, H_2 gas (100 sccm) was maintained for 10 min at growing temperature. Then, the samples were cooled down to room temperature in the flow of Ar gas (300 sccm).

Figure 1 shows SEM images of the VA-CNTs film grown on Cu substrates with thickness of (A) Fe – 4 nm; (B) Cr – 4 nm. We found that the Fe catalytic film with a thickness ranging from 3 nm to 5.5 nm is suitable for growing VA-CNTs on Cu substrates. In contrast, on the samples with the Cr thickness of lower than 4 nm, the CNTs are not aligned (not shown here). Meanwhile, on the samples with the Cr thickness of higher than 4 nm, the CNTs are aligned (Figure 1(B)). The SEM images (Figure 1) indicate that density of the VA-CNTs on Cu substrate is very high and the length of the CNTs is in the range of 20–30 μm. Figure 2 shows that the CNTs grown on the Cu substrate are clean and the diameter of the CNTs is in the range of 15–25 nm.

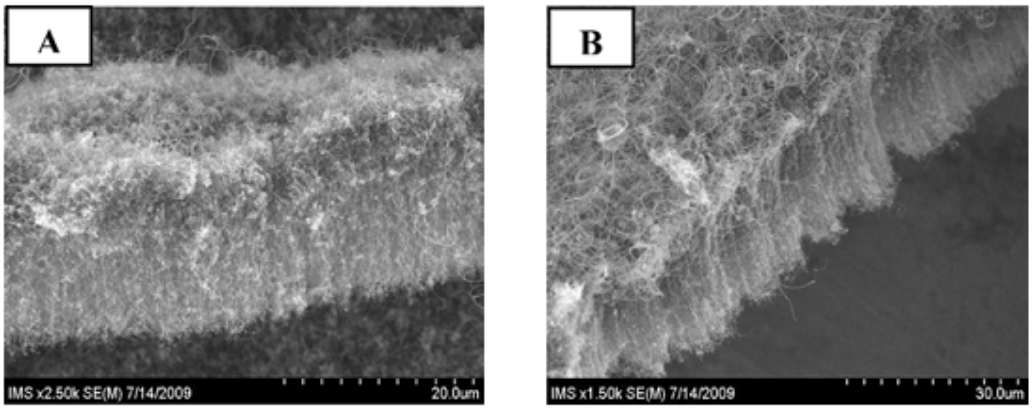

Figure 1. *SEM images of VA-CNTs grown on (A) Fe/Al/Cu substrate with Fe thickness of 4 nm and (B) Cr/Al/Cu substrate with Cr thickness of 4 nm*

*** Transferring VA-CNTs layer grown on Si/SiO_2 substrate to Cu substrate:**

Besides the method of directly growing the VA-CNTs on Cu substrate as mentioned above, we developed a technique to transfer the VA-CNTs layer from Si to Cu substrates. First, we synthesised the VA-CNTs film on the Si/SiO_2 substrate. Then, we transferred the VA-CNTs layer from the Si/SiO_2 substrate to the Cu substrate. The VA-CNTs film was synthesised on the Si/SiO_2 substrate by CVD method using Fe_3O_4 particles as the catalyst. The Fe_3O_4 nanoparticles were formed by the co-precipitation reaction of iron salts. The Fe_3O_4 particles, which had diameters from 10 to 20 nm, were uniformly coated on the surface of Si/SiO_2 substrate by spin-coating method. The SEM image (Figure 3(A)) indicated that the Fe_3O_4 nanoparticles were located on the surface of the Si/SiO2 substrate with a high density of approximately 10^{10} – 10^{12} cm^{-2}. The AFM image (Figure 3(B)) showed that the diameters of the Fe_3O_4 nanoparticles were in the range of 10–20 nm.

The VA-CNTs were grown on Si/SiO_2 substrate at different growing temperatures using a mixture of $N_2/H_2/C_2H_2$ gases with ratio of 300/100/30 sccm. We found that the alignment of the CNTs strongly depend on the growth temperature. At a temperature of lower than 650°C, the CNTs were less well aligned (not shown here). The orientation of CNTs changed from a random spaghetti-like distribution for CNTs grown at 650°C to a vertical forest-like alignment for CNTs grown at 750°C. Figure 4(A) shows a typical SEM image of the CNTs on SiO2/Si substrate grown at 750°C for 30 min. It is clear that the nanotubes are well aligned and uniform in height. The height of the VA-CNTs is approximately 15 μm. A typical TEM image (Figure 4(B)) of the CNTs sample grown for 30 min at 750°C shows that the CNTs are clean with diameters of approximately 15 nm.

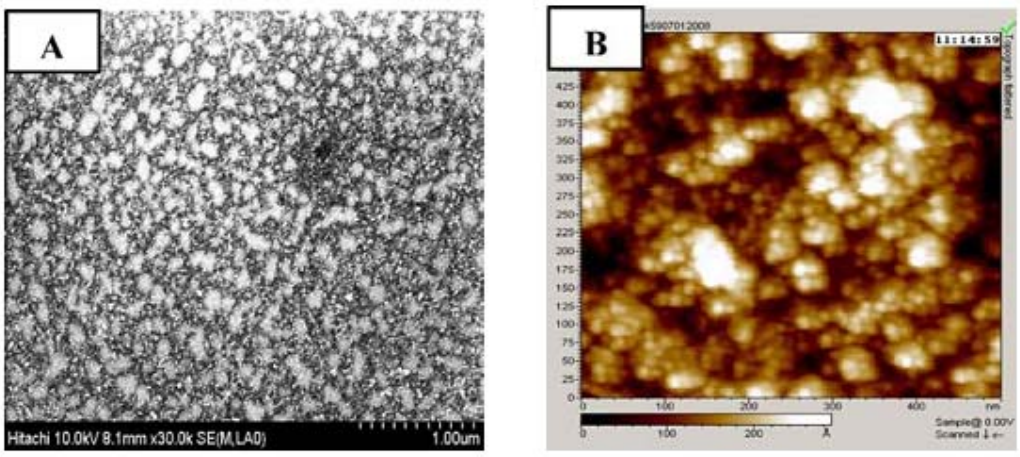

Figure 3. *(A) SEM and (B) AFM images of the Fe3O4 nanoparticles on the Si/SiO2 surface (see online version for colours)*

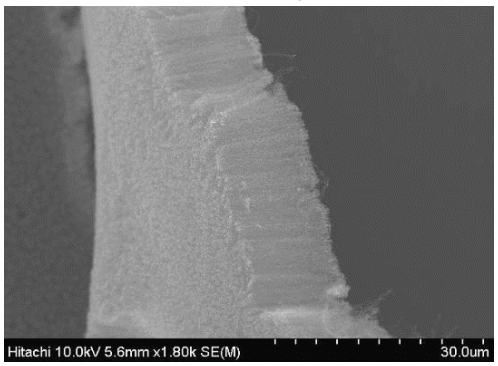

Figure 4. *SEM image of the VA-CNTs*

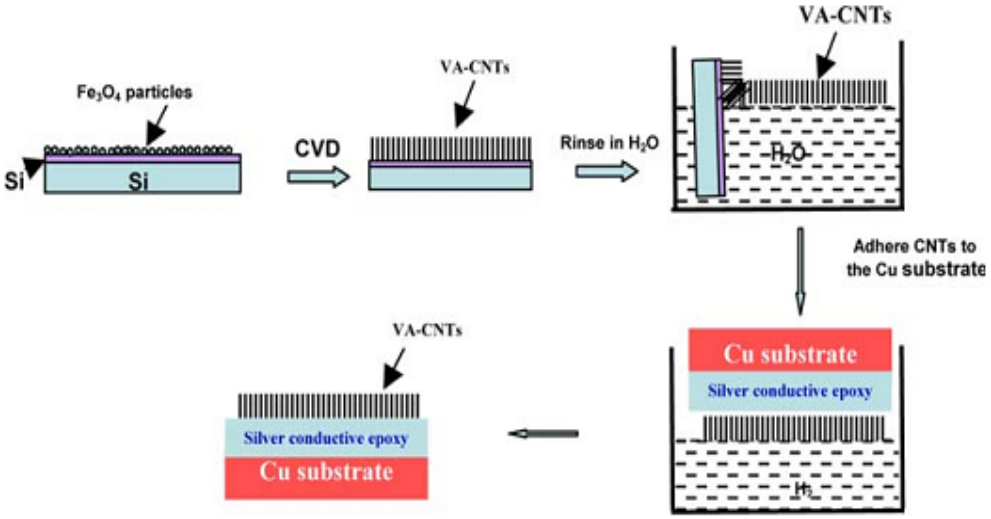

Figure 5. *Schematic view of the transfer of the VA-CNTs layer from Si/SiO$_2$ substrate to Cu substrate*

Figure 5 is a schematic diagram of the process to transfer the VA-CNTs layer from the Si/SiO2 substrate to the Cu substrate. The synthesised VA-CNT film was detached from the

Si/SiO_2 substrate by directly immersing the sample into distilled water at a temperature of 60°C with the slow rate of 2~5 mm/s. The process of detaching the VA-CNTs film from the Si/SiO_2 substrate is also reported in detail in [8]. The floating VA-CNTs film was then attached to the silver conductive epoxy coated Cu substrate. By using this technique, the VA-CNTs were successfully transferred to the Cu substrate.

b) Application of the VA-CNTs film for LED chips

The synthesised VA-CNTs were utilised as heat spreaders to reduce the local temperature of high-power electronic devices. The LED chip used in this work was an InGaN on sapphire with an active area; emitting light wavelength and working power of 0.5 mm × 0.5 mm, 460 nm and 0.5 W, respectively. Figure 6 shows a schematic view of the LED package using the VA-CNTs as thermal dissipation materials. They were inserted as a heat spreader between the device and the copper heat sink. The VA-CNTs were adhered to the Cu substrate by good thermal conductive material (Arctic silver 5 M or 3 M thermal bonding film). It is expected that the VA-CNTs will reduce the local temperature in high-power LEDs.

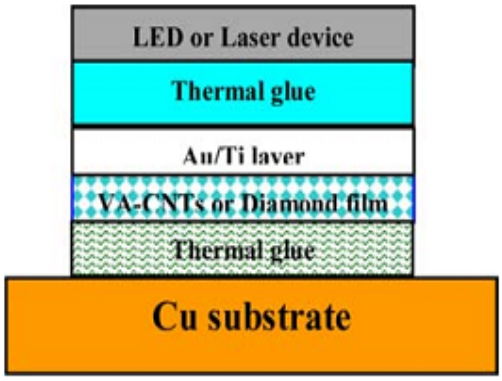

Figure 6. *Schematic view of the LED using thermal dispersive VA-CNTs or diamond film*

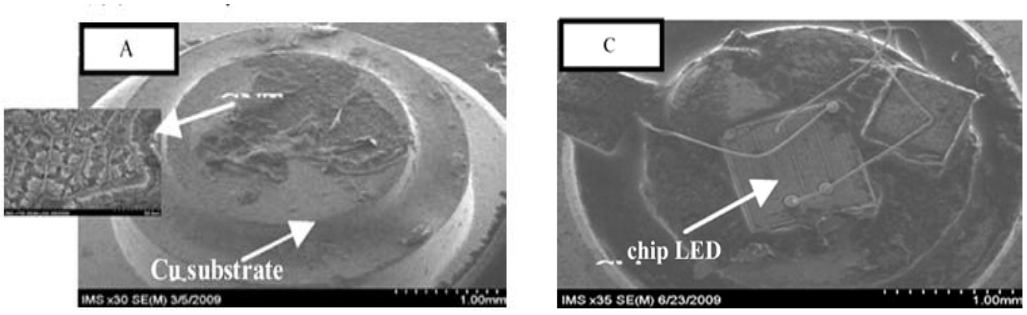

Figure 7. *(A) SEM images VA-CNTs layer on Cu substrate; (B) the LED chip adhered to the VA-CNTs film*

Figure 7(A) is the SEM image of the VA-CNTs film on Cu substrate before assembling the LED chip. Figure 7(C) is a typical SEM image of the VA-CNTs on Cu substrate after assembling and wiring the LED chip on the VA-CNTs/Cu substrate.

The output light power of the LED packages should ideally maintain a linear relationship with the electrical input current if the heat generated from the LED modules can be effectively dissipated. However, heat generated by high input power would degrade the LED optical performance and result in a saturation of output light power. Normally, for the InGaN LED chip used in this experiment, the light power of the LED packages using the commercial thermal dissipation material starts to deviate from a linear relationship with the input current about 300 mA and reaches a peak value at 350 mA. By using VA-CNTs film instead of the commercial thermal dissipation material, the output light power of the LED packages retains a linear profile without reaching saturation even if the input current is higher than 500 mA and 350 mA, respectively. These results indicated that the VA-CNTs film act as an excellent heat spreader layer that rapidly dissipates heat from the heat source (LED). Our initial result confirmed that the VA-CNTs film strongly improve thermal dissipation property and can be used in high-power electronic devices.

2. Fabrication CNTs/Cu and CNTs/In composite for thermal dispersion

a) Fabrication of CNTs/Cu composite

The Cu/CNTs nanocomposites were fabricated by powder metallurgy method and some of mechanical properties such as hardness, wear resistance and friction coefficient of the Cu/CNTs nanocomposites were characterized. Figure 8 shows a schematic view of the synthesis process base on powder metallurgy method.

Atomized commercial purity (99.9%) copper powders of 2-3 μm in diameter produced by PEAXNM Co. were used for a matrix material. Multi-walled carbon nanotubes (MWCNTs) produced by a chemical vapor deposition (CVD) process, with an average of about 50 nm in diameter and 50 μm in length were used as additive component.. In order to improve the dispersion of CNTs in acetone, CNTs were treated in hot acid (H_2SO_4:HNO_3, 3:1) at 60^0C for 4 hour.

The micro-sized Cu powder and the CNTs dispersed in acetone were mixed into nanocomposites powder through a high-energy ball milling process using planetary miller for 6 h with 300 rpm. The ratio of CNT varies from 0% (wt.) to 3% (wt.). The mixture of CNTs and copper powder was pressed in steel dies under a compress force of 2.5 tons/cm^3 for 30 seconds.

The specimens were isothermally sintered at 100^0C for 1h and 900^0C for 2 hours in pure argon atmosphere. The size of the testing specimens, containing 0 to 3 wt. % of CNTs, are 20 mm in diameter and 10 mm in height.

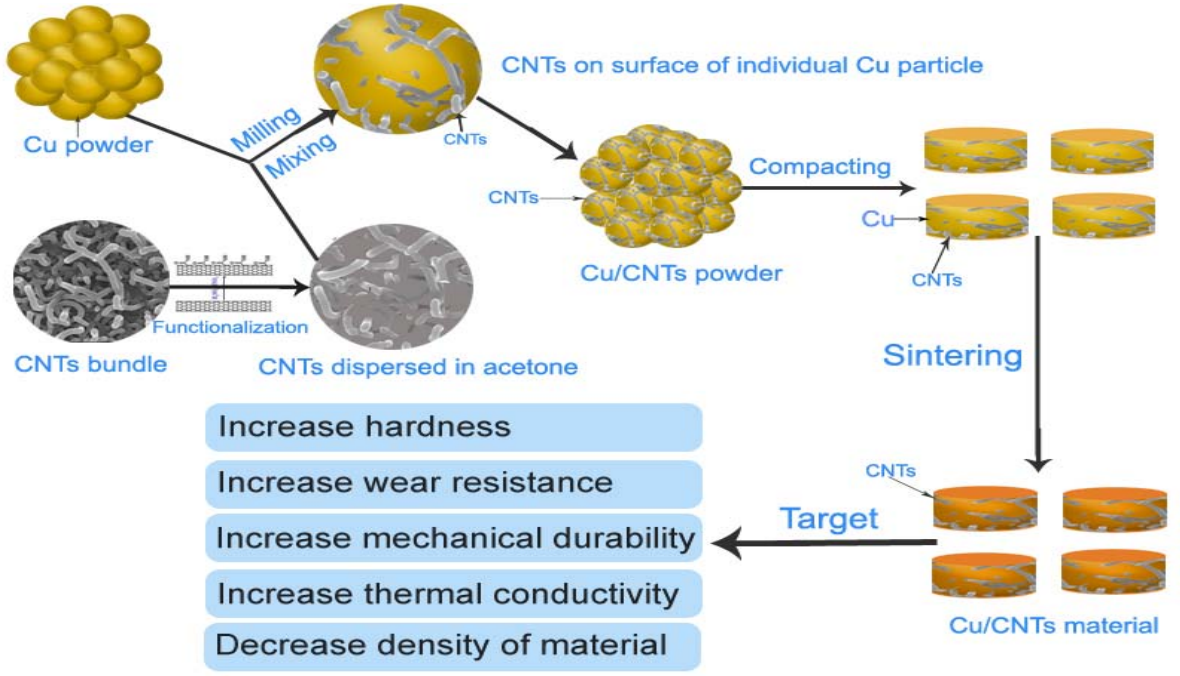

Figure 8. *Schematic view of the of Cu/CNTs nanocomposites fabrication process based on powder metallurgy method*

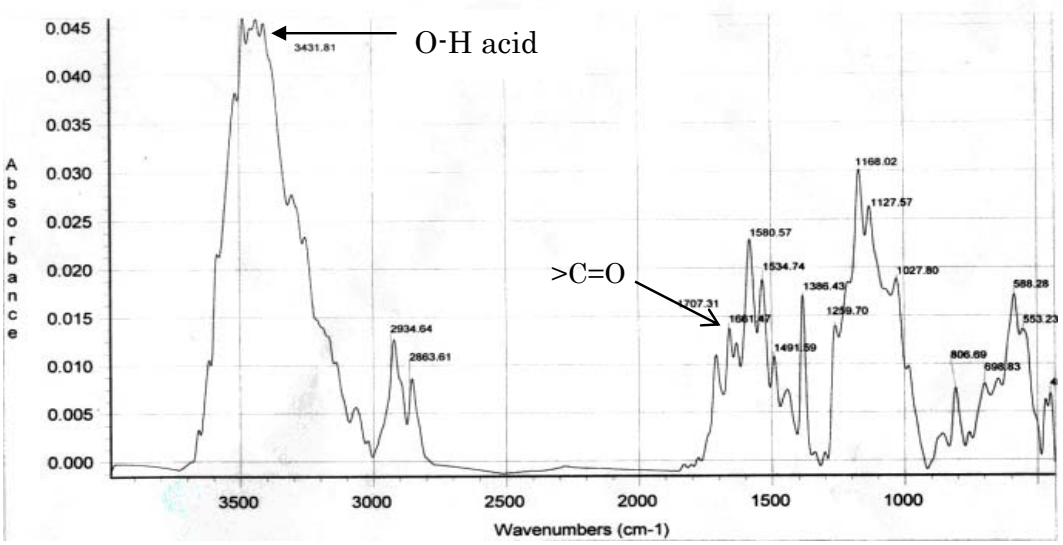

Figure 9. *The FIR spectrum of CNTs functionalized by mixture of H_2SO_4 and HNO_3 acid with 3:1 mol ratio*

The key point of this work is to improve the uniformity in dispersion of the CNTs in the Cu matrix. To achieve this target the CNTs were chemically functionalized in H_2SO_4:HNO_3 (3:1) at 60^0C for 4 h, so that the CNTs were well dispersed in acetone solution. The existence of carboxyl (COOH) functional groups bonded to the ends and sidewalls, was demonstrated by FIR spectral and shown in Fig 9. The Cu powders were poured into the CNTs-acetone solution. By evaporating the acetone, the CNTs were wrapped on the surface

of each Cu particle. The Cu/CNTs nanocomposite powders were fabricated by high-energy ball milling process using planetary miller. The fabricated Cu/CNTs nanocomposite powders were consolidated into bulk Cu/CNTs nanocomposite by compacting and sintering process. The composites with a high mass fraction of CNTs exhibited high porosity by structure of CNTs.

Figure 9 shows some important peak after MWCNTs was treated by mixture of H_2SO_4 and HNO_3. The vibration of O-H bonding in cacboxyl group was shown on peak 3431.81 cm^{-1}. It expanded more than to compare with O-H bonding of H_2O. Peak 1707.31 cm^{-1} shown that the existence of vibration of C=O bonding in cacboxyl group. This is exhibited important to prove the existence of carboxyl (COOH) functional groups appeared due to the oxidation resulting from nitric and sulfuric acids. It clearly shows that the kinds of acids functionalized the surface of MWCNTs.

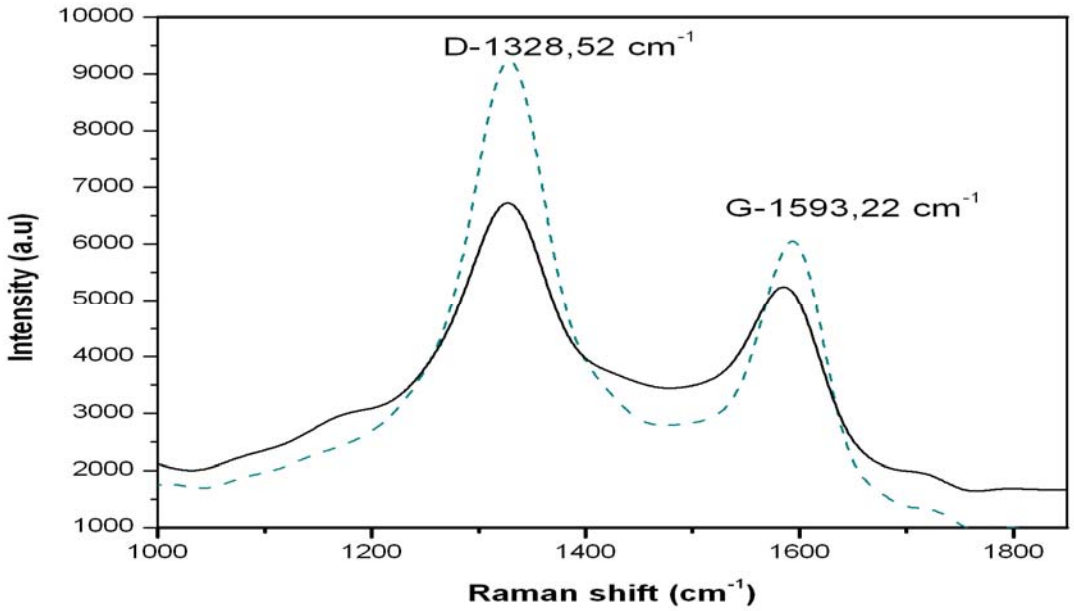

Figure 10. *The Raman spectra for the raw and carboxylically functionalized MWCNTs*

Fig. 10 is the Raman spectra for the raw and carboxylically functionalized MWCNTs. It is clearly seen from Fig. 10 that the two bands around 1593 and 1328 cm^{-1} in the spectra were assigned to the tangential mode (G-band) and the disorder mode (D-band), respectively [9,10]. The D-band intensity was increased in themodified MWCNTs compared to raw MWCNTs. The peak intensity ratio (I_D/I_G= 1.60) at D-band and G-band for the modified MWCNTs exceeded those of raw MWCNTs (I_D/I_G= 1.27). This result indicates that some of the sp^2 carbon atoms (C=C) were converted to sp^3 carbon atoms (C-C) at the surface of the MWCNTs after the acid treatment in H_2SO_4/HNO_3.

The fabricated Cu/CNTs nanocomposite powders are consolidated into bulk Cu/CNTs nanocomposite with full densification (above 86%) as shown in Table 1 by compacting and sintering process. The composites with a high mass fraction of CNTs exhibited high porosity by structure of CNTs. Therefore, the density of Cu/CNTs

nanocomposites will be decreased as the results showed in Table 1. The optical image of consolidated Cu/CNTs nanocomposite specimens is displayed in figure 11(a) and the surface morphology of 1 wt.% Cu/CNTs nanocomposite is shown in figure 11(b). It shows homogeneous distribution of carbon nanotubes within the Cu matrix and homogeneous implantation CNTs on the surface of individual Cu particles.

Table 1. *Relative densities of CNT/Cu nanocomposites with wt. % of CNTs*

Weight percent of CNTs	Measured density (g/cm^3)	Theoretical density (g/cm^3)	Relative density (%)
0 %	7.655	8.920	86
1 %	7.460	8.456	88
2 %	7.339	8.055	91
3 %	7.160	7.682	94

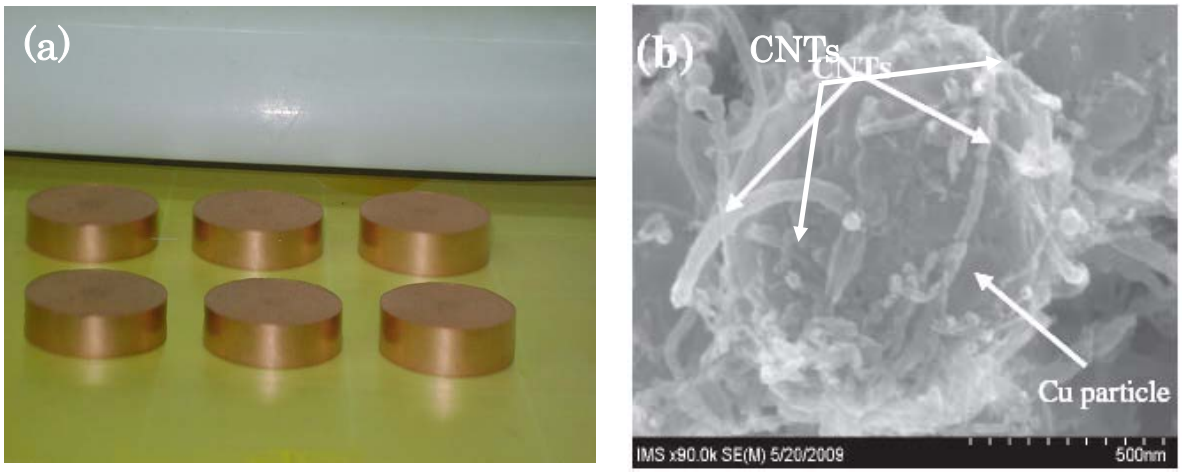

Figure 11. *(a) optical image (b) surface morphology of Cu/CNTs nanocomposites with 1wt% of CNTs*

The hardness of the composites with different mass fractions of the CNTs is shown in figure 12. The hardness was measured by Brinel hardness test. A considerable enhancement of the hardness is observed by addition of the CNTs in the Cu matrix. The hardness increases almost linearly with increasing of the CNT mass fraction up to 3 %. At 3.% (wt) of CNTs are reinforced, the hardness of the Cu/CNTs nanocomposites reach to a value of 38.9HB, which is about 1.13 times higher than that of the Cu without CNTs. To explain the carrying capacity of the Cu/CNTs nanocomposites, we assumed that Cu matrix has ability transfer and distribute external force to the reinforcement material. The external force loaded on the Cu matrix itself is reduced. Here, the reinforcement material is CNTs, which have high strength so that the Cu/CNTs nanocomposites have mechanical durability greater than that of the pure Cu matrix.

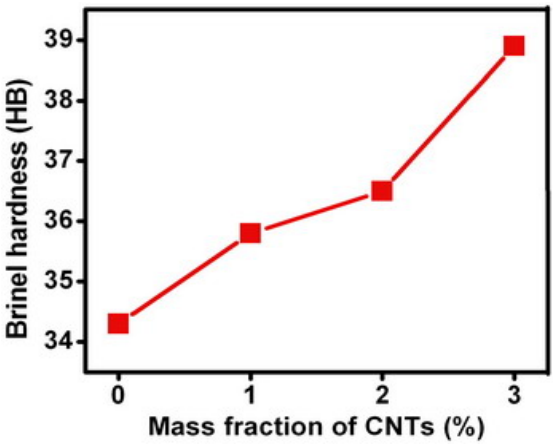

Fig. 12*. Dependence of the Brinel Hardness (HB) of the Cu/CNTs composite on mass fraction of the CNTs*

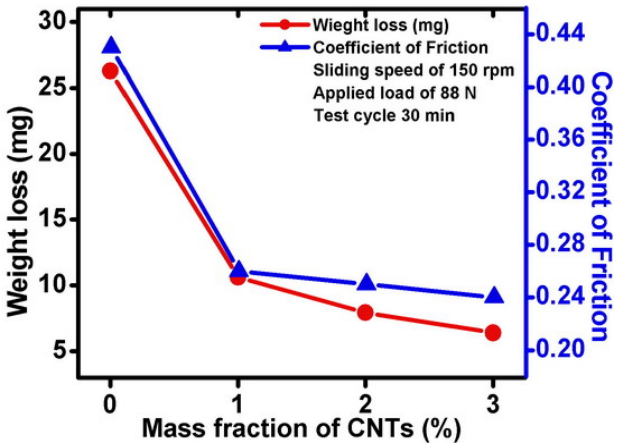

Fig 13. *The variation of wear properties and friction coefficient of the Cu/CNTs nanocomposites with varying the mass fraction of the CNT*

Figure 13 shows the variation of wear loss for the Cu/CNTs nanocomposites with the mass fraction of CNTs at a sliding speed of 150 rpm, at applied load of 88N and the test cycle for each run was 30 min. Within the range of mass fraction of the CNTs from 0% to 3%, the wear loss of the composite decreased with increasing the mass fraction of the CNTs in the composite. The favorable effects of the CNTs on wear resistance are attributed to their excellent mechanical properties, well dispersion in the composite and the efficiency of the reinforcement of the CNTs. The friction coefficient of the Cu/CNTs nanocomposite as a function of mass fraction of the CNTs was measured as shown in figure 13. We can see that the friction coefficient decreases with increasing the mass fraction of the CNTs in the composite. The friction coefficient of the Cu/CNTs nanocomposite decreases 1.9 times than that of the sintered Cu without CNTs. It suggested that an increase in surface fraction of the CNTs reduces the direct contact between the Cu matrix and steel pin. Due to self-lubrication of the CNTs, the short and tube shape of the CNTs would more easily slide or roll between the mating metal surfaces, thus resulting in the decrease of the friction coefficient of the composite.

The synthesiszed Cu/CNTs nanocomposite were used as heat sink substrate for LED packaging as shown in figure 14. Initial experimental results show that LED temperature decrease of approximately 5^0C at the saturated current of the LED when using this Cu/CNTs composite heat sink compared to the conventioal Cu substrate. This confirmed the heat sink is also important for the system and the Cu/CNTs is suited for this perpose.

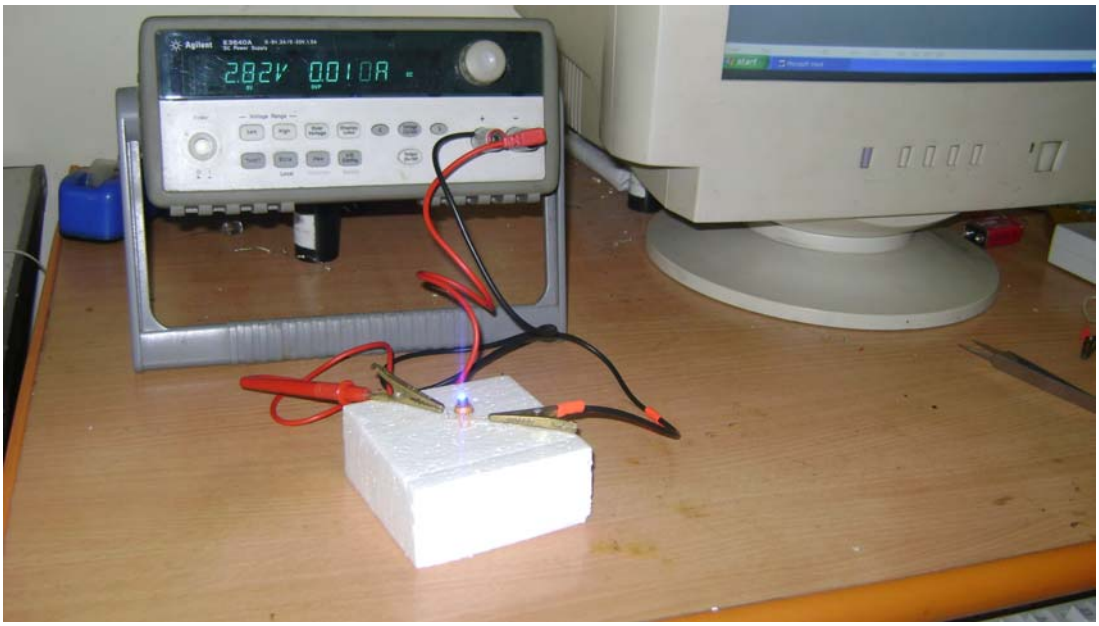

Fig 14. *Cu/CNTs composite used to make the LED heat sinks*

b) Fabrication of CNTs/In composite

Beside fabrication of CNTs/Cu composite, we intend to use CNTs/In composite to enhance the thermal efficiency for HB-LEDs. In the first case, the functionalized CNTs material will be entirely covered on the surface of indium particles. Then the CNTs/In particles are placed between the HB-LED chip and heat sink. The CNTs/In particles are stuck with HB-LED chip and heat sink by heating shown as in figure 15. In these configurations, the CNTs will play as the thermal dissipation channels, Indium plays as sticking metal to seal the LED chip on the heat-sink.

The process of manufacturing materials In/CNTs nanocomposite is shown in figure 18. Chemical deposition method was used for manufacturing materials In/CNTs nanocomposite. The original materials used to create the In/CNTs composite is indium salts and CNTs (a). Fabrication process consists of seven basic steps:

- Functionalized CNTs are modified by chemistry method with additional organic functional groups onto the surface of carbon nanotubes as -OH, -COOH. Functionalized CNTs material has strong dispersion in the type of environment such as water, organic solvents.

- Dispersed functionalized CNTs material the soluble solvents compatible with the organic functional groups attached to carbon nanotubes.

- Indium salt solution made from indium salts.

- Indium salt solution are mixed with a solution containing CNTs modified material

forming a liquid mixture of saline solution containing indium and modified CNTs by heating and stirring methods.

- Deposition process of creating materials: NH_3 is used to precipitate $In(OH)_3$ - CNTs, NH_3 are dropped slowly in solvents salt containing indium and modified CNTs, the stirring and heating was maintained in the process.

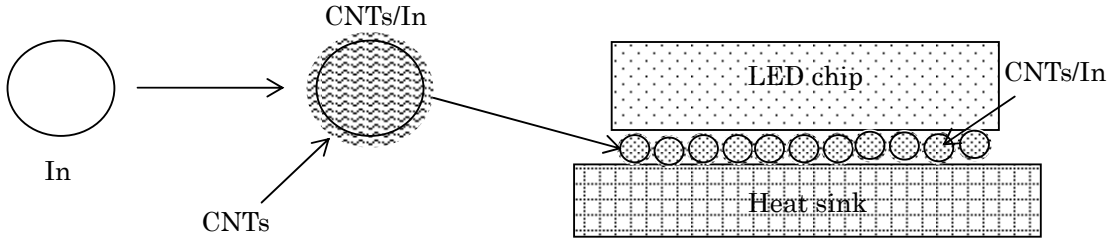

Figure 15. *HB-LED with heat dissipation using CNTs/In composite layer*

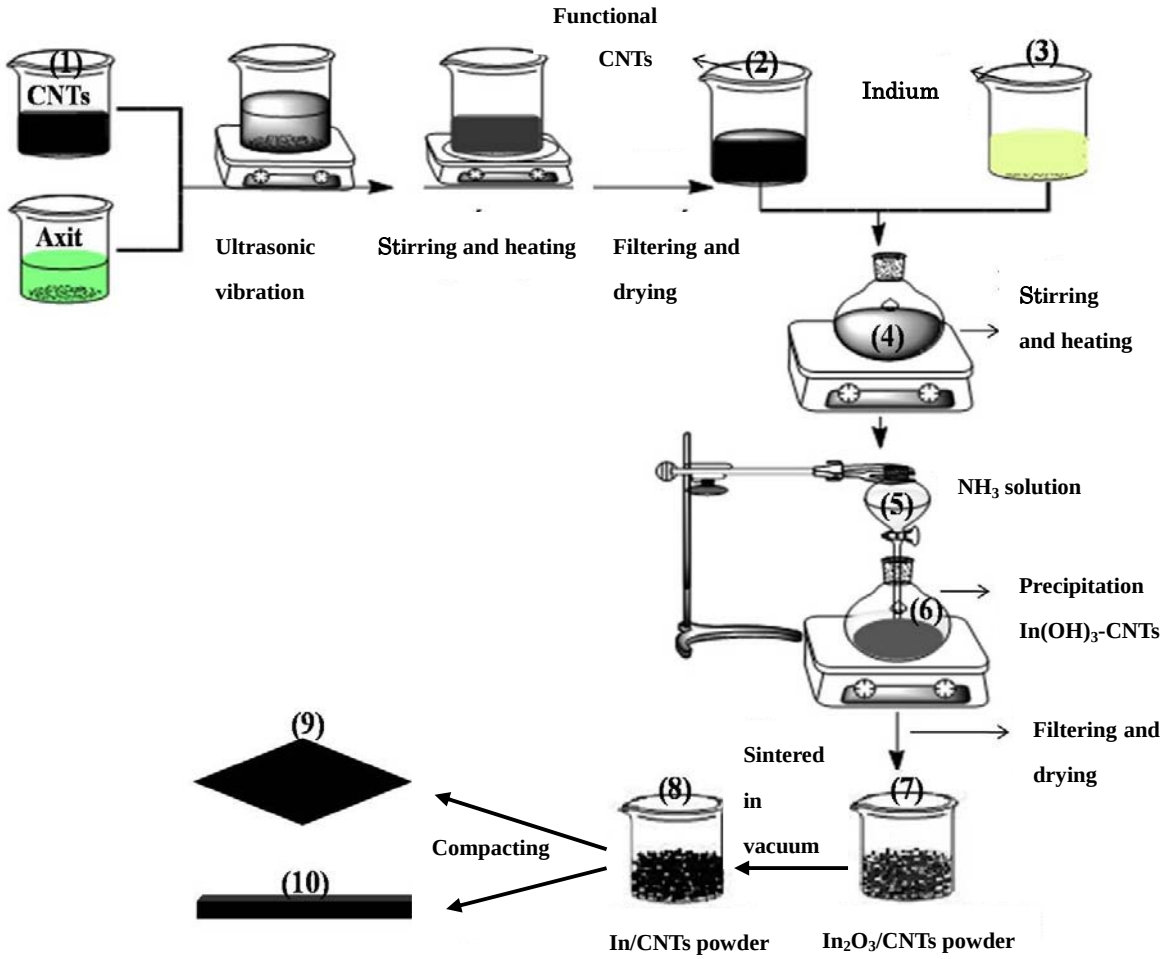

Figure 16. *The process of fabrication CNTs/In composite*

- We obtained functionalized CNTs material precipitates dispersed in the $In(OH)_3$, the mixture material filtered with distilled water, then dried in air environment. After drying in air environment we obtained mixed powder material is In_2O_3/CNTs materials.

- Material obtained was sintered in a vacuum to remove the organic components exist in the material was created. Finally, the material obtained was In/CNTs nanocomposite powder. This material In/CNTs nanocomposite powder is a collection of many particles. In this composited containing functionalized CNTs surrounding the outer surface of the particle as well as deep within the indium particles created by the deposition process in solvents containing modified CNTs distributed evenly.

Material used for this research were $In(NO_3)_3.3H_2O$ salt (Merck – Germany with 99.99% purity). CNTs material was made at Institute of Materials Science by CVD method with over 95% purity, 50 - 70 nanometers in diameter and 5 - 10 μm in length.

Fabrication process consists below steps:

Step 1: CNTs materials were mixed with H_2SO_4 and HNO_3 acids, concentration ratio of 3:1 by mol /l to obtained CNTs-COOH materials.

Step 2: Dispersion CNTs-COOH in distilled water by heating and stirring.

Step 3: $In(NO_3)_3.3H_2O$ salt was dissolved in saline to obtain solution $In(NO_3)_3$. This solution is mixed with CNTs-COOH solution by stirring and heating.

Step 4: Drop NH_3 solution (pH = 9.5) into the mixed salt solution of In $(NO_3)_3$ and CNTs-COOH to form precipitates in the $In(OH)_3$ - CNTs.

Step 5: Precipitation $In(OH)_3$-CNTs were washed and drying the powder material obtained $In(OH)_3$-CNTs.

Step 6: In/CNTs nanocomposite powder obtained after $In(OH)_3$-CNTs was sintered in a vacuum.

Figure 17 showed the indium powder with CNTs materials surrounding the outer surface of the particles In.

c) Applying In/CNTs composite in HB-LED

Normally, the 1 W OSRAM LED chip used in this experiment is showed as figure 18. The CNTs/In composite was filled between surfaces of Aluminum Substrate and LED, and then used at high temperature (200^oC) to melt indium to mount Aluminum Substrate and LED showed as figure 20 and figure 19.

Figure 17. *SEM Image of CNTs/In powder.* ***Figure 18.*** *1W OSRAM LED used in research*

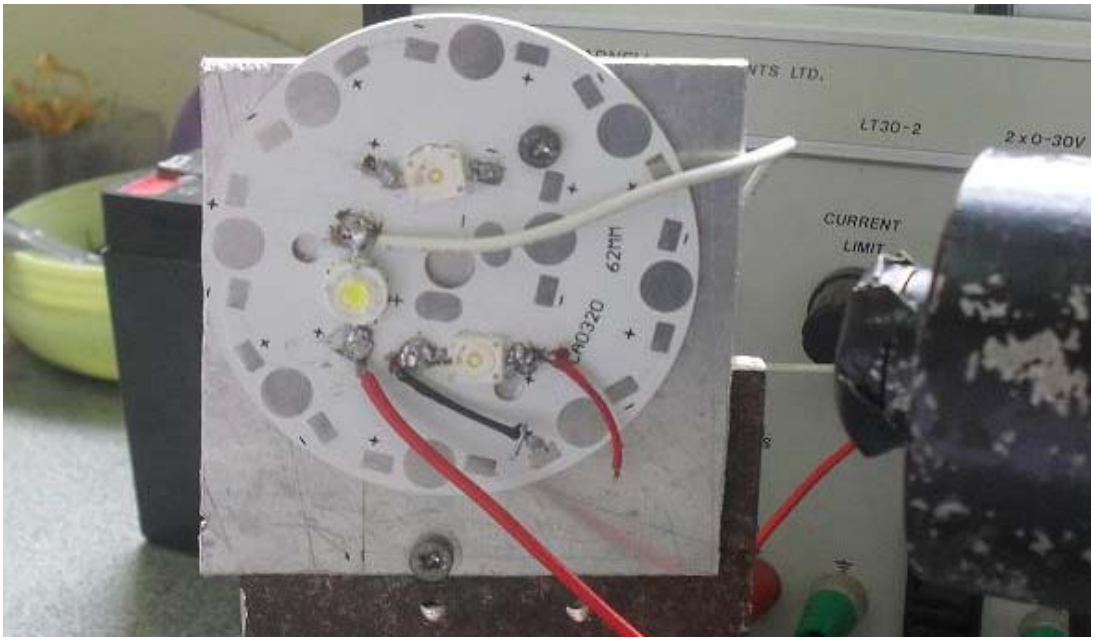

Figure 19. *1W OSRAM LED on Aluminum Substrate using CNTs/In composite as the thermal layer*

We used MELLES GRIOT 13PEM001 to measured illuminating power at constant voltage. LED operated at 3.5 V and ambient temperature is 20^{o}C. Figure 20 showed experiment setup to measure optical power.

The initial results showed that the illuminating power increases from 25.6 mW (when using thermal paste between LED and substrate) to 26.2 mW when using when using CNTs/In composite. Other hand, power consumption of LED reduced from 1.1 W to 0.87 W when using CNTs/In composite. The results have confirmed the advantage of CNTs/In as excellent component for thermal dissipation media in the HB-LED and other high power electronic devices.

Figure 20. *MELLES GRIOT 13PEM001*

III) Conclusions

The VA-CNTs film on Cu substrates was successfully synthesised. An effective method was successfully developed to transfer the VA-CNTs film from the Si substrate to Cu substrate. The diameter of carbon nanotubes and the thickness of the vertically aligned carbon nanotube film were in the range of 10–30 nm and 10–30 μm, respectively. The light performance of the light emitting diode (LED) packages using the VA-CNTs film was tested on an InGaN LED chip. The VA-CNTs film maintained a linear relationship of the output light power without reaching saturation for the LED chip of 0.5 W InGaN, compared with the packaged device using commercial silver thermal paste. The VA-CNTs film greatly increased the input LED current, about more than 500 mA and 350 mA, respectively. This

result indicates that the light output power was greatly improved with the use of the VA-CNTs film. Initial results from the LED-0.5 W InGaN experiment demonstrated that the VA-CNTs film is optimal choices for the thermal dissipation of HPED.

A homogeneous distribution of MWCNTs in a copper matrix has been achieved by a novel processing approach based on the precursor method for the synthesis of copper and acid-treated MWCNTs. The dispersion of the CNTs in Cu matrix is very important, even determined nanocomposite material properties such as to enhance the mechanical behavior and wear resistance of the Cu/CNTs nanocomposites. The successful functionalization of the nanotubes with mixture of acid solution proved by FIR spectrum was opened up new applications in composites field. The hardness and wear resistance of fabricated Cu/CNTs nanocomposites were significantly increased with increasing the mass fraction of CNTs. The Cu/CNTs nanocomposites with high quality may have potential applications to tribomaterials such as electric contacts, metal graphite brushes, and electric poles, etc…

IV. List of publication and other results related to the work

1. Papers published on the international journal:

- "Synthesis of vertically aligned carbon nanotubes and diamond films on Cu substrates for use in high-power electronic devices", Nguyen Van Chuc, Ngo Thi Thanh Tam, Nguyen Van Tu, Phan Ngoc Hong, Than Xuan Tinh, Tran Tien Dat and Phan Ngoc Minh, **Int. J. Nanotechnol.,** Vol. 8, Nos. 3/4/5, 2011, pp. 188 – 200
- "Thermal dissipation media for high power electronic devices using a carbon nanotube-based composite", Hung Thang Bui,Van Chuc Nguyen, Van Trinh Pham, Thi Thanh Tam Ngo and Ngoc Minh Phan, **Adv. Nat.S ci. :Nanosci. Nanotechnol.** 2 (2011)0 25002 (4pp), doi:10.1088/2043-6262/2/2/025002
- "The effect of sintering temperature on the mechanical properties of a Cu/CNT nanocomposite prepared via a powder metallurgy method", Van Trinh Pham, Hung Thang Bui, Bao Trung Tran, Van Tu Nguyen, Dinh Quang Le, Xuan Tinh Than, Van Chuc Nguyen, Dinh Phuong Doan and Ngoc Minh Phan, **Adv.Nat.Sci.: Nanosci.Nanotechnol.** 2 (2011)015006(4pp), doi:10.1088/2043-6262/2/1/015006

2. Submited patent to Vietnam Intellectual Agency, Ministry of Science and Technology:

- Phan Ngoc Minh, Bui Hung Thang, Nguyen Van Chuc, Pham Van Trinh, Phan Ngoc Hong, Doan Dinh Phuong, "Fabrication and application In/CNTs composite materials in thermal dissipation for high power electronic devices", Application No. 1-2011-03526 SC, Date: December 19, 2011 (in Vietnamese).

3. Eduacations:

- Bui Hung Thang, "Simulation and experimental thermal dissipation for μ-Processor applying carbon nanotubes ", Vietnam National University, Hanoi, Master degree 2011.

- Pham Van Trinh, “Fabrication and characterization of the properties of Cu/CNTs nanocomposite”, Vietnam National University, Hanoi, Master degree 2011.

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